Gas Temperature Measurements with High Temporal Resolution

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Gas Temperature Measurements with High Temporal Resolution

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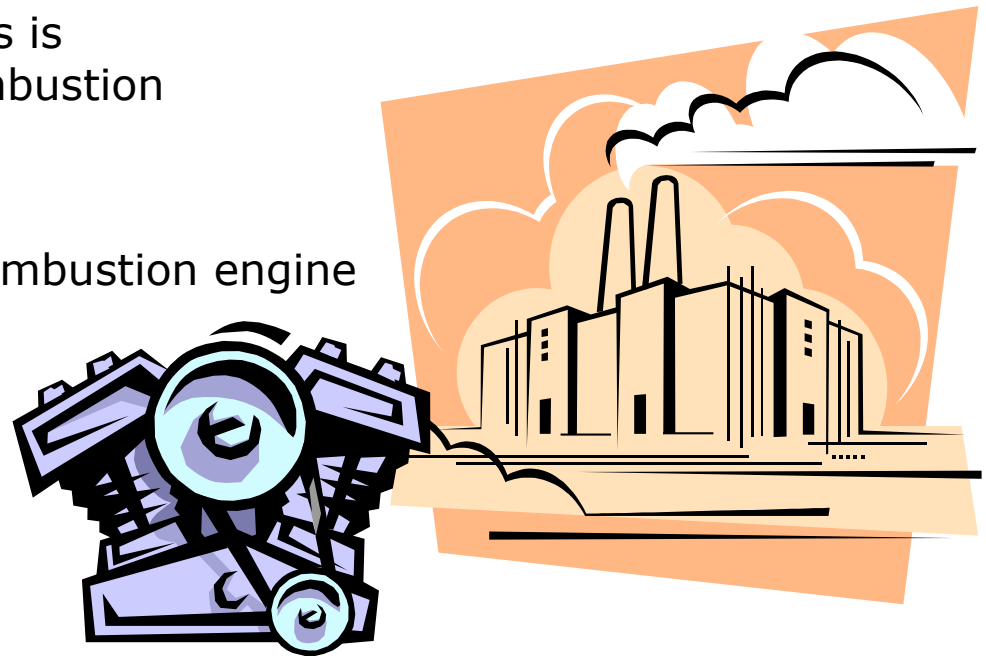
Introduction

- The temperature of the flue gas is an important parameter of combustion
  - e.g. inside
    - a boiler of a power plant
    - cylinder of an internal-combustion engine
    - etc.



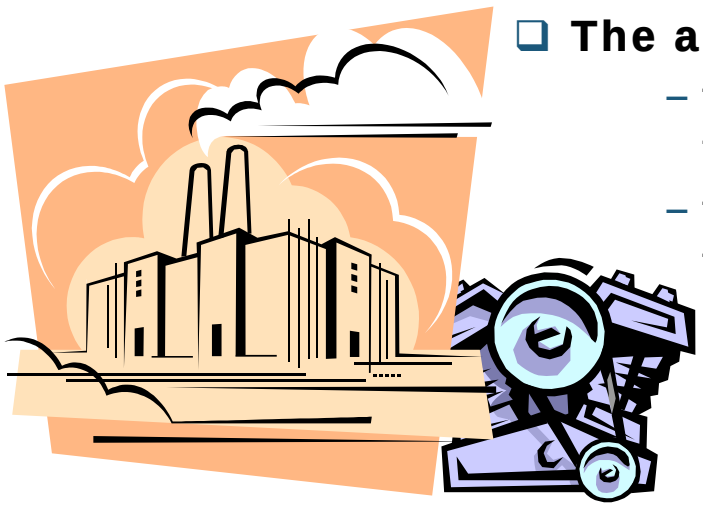
- High spatial and temporal resolution is essential for accurate modeling of the process

- The analysis helps in
  - further development of the models
  - optimization of boiler/engine design
  - etc.

Introduction

Lab

- Investigations under convenient laboratory conditions
  - are not sufficient to verify the models for industrial combustors
- Laser techniques offer great opportunities for combustion research but
  - involve complicated and expensive set-up
  - are demanding to alignment
  - require more man-hours



- **The aim of this work is**
  - to achieve high enough temporal resolution for flue gas temperature measurement
  - to be able to apply commercially the technique on industrial scale

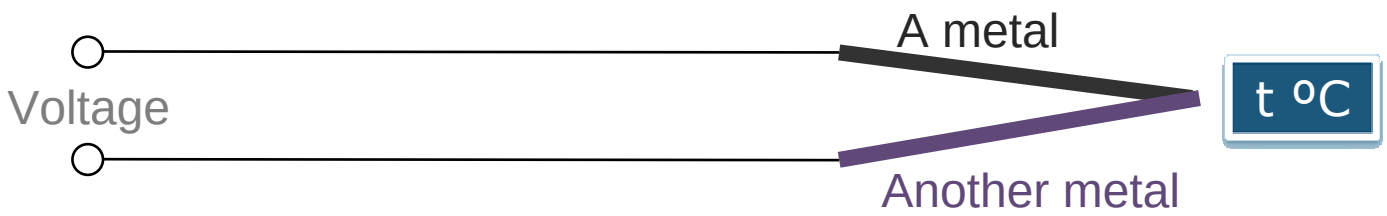
Industry

Outline

- **Existing methods**
  - Contact
  - Non-contact
- **The new system**
  - Non-contact
    - Optics + Grating spectrometer + IR Camera
- **Application on the industrial boiler**
  - Measurement of the flue gas temperature with high temporal resolution
- **Future of the system**
  - Multichannel spectrometer
  - 2D Tomography of a flame

Thermocouples

- Any junction of dissimilar metals will produce an electric potential related to temperature.

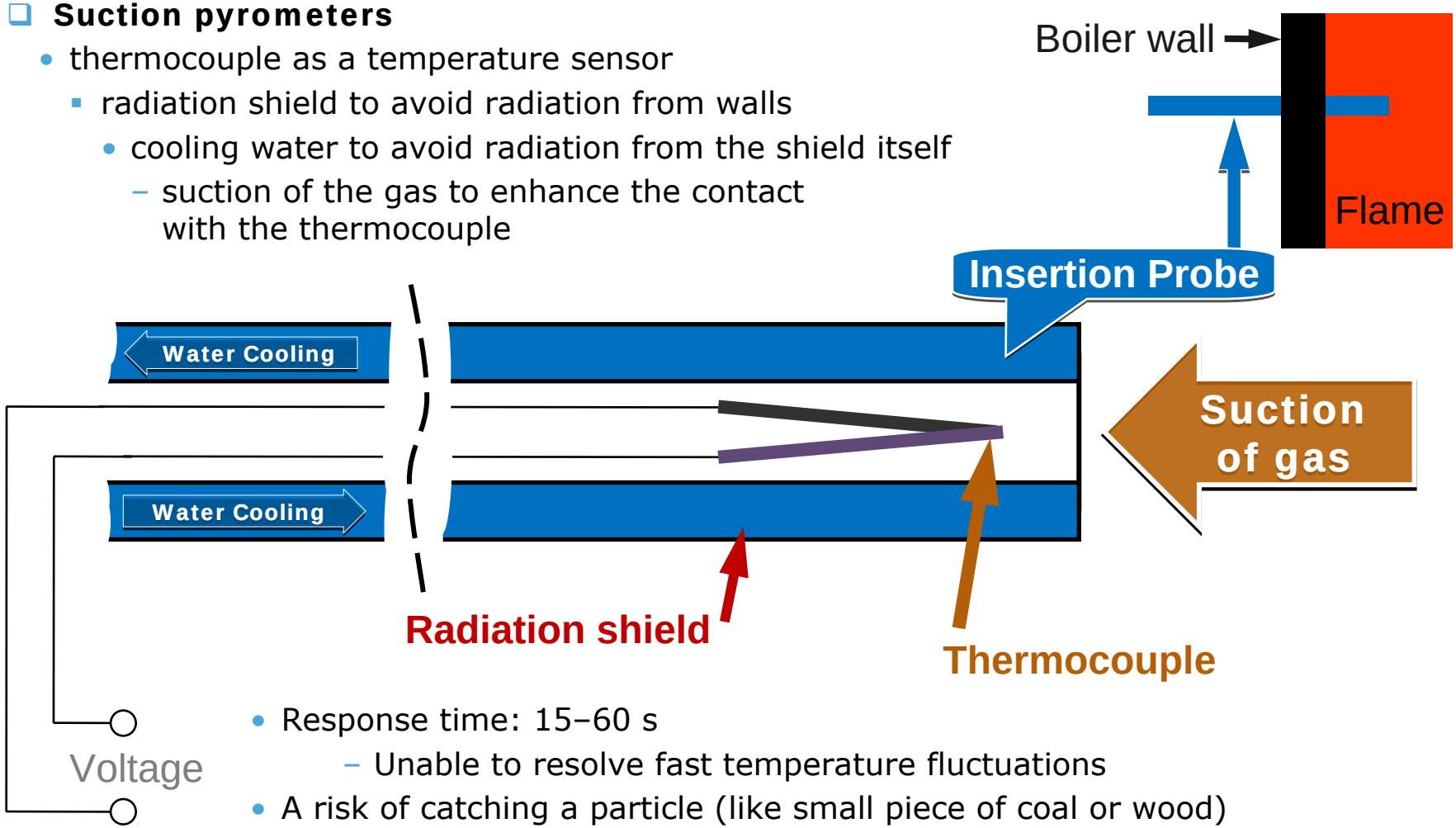


  - inexpensive
  - can measure a wide range of temperatures
  - very simple setup
  - reliable results

- **A thermocouple measures its own temperature.**
  - It gives somewhat integrated temperature of what it is in contact with.
  - Response time: 15–60 s.

Contact Methods

- **Suction pyrometers**
  - thermocouple as a temperature sensor
    - radiation shield to avoid radiation from walls
      - cooling water to avoid radiation from the shield itself
        - suction of the gas to enhance the contact with the thermocouple



- Response time: 15–60 s
  - Unable to resolve fast temperature fluctuations
- A risk of catching a particle (like small piece of coal or wood)
  - Resulting in false temperature reading

Spectroscopy

- **Absorptivity**:
  - How much of incident energy is absorbed at a certain wavelength λ?

$$\alpha_\lambda(T) = \frac{I_\lambda^0 - I_\lambda}{I_\lambda^0}$$

- However each sample also emits radiation by means of thermal radiation:
  - $R_\lambda(T)$ – **spectral radiance** [W / (m^2 sr m)]
  - How does the sample having temperature T emits radiation at a certain wavelength λ?

- Kirchhoff established:
  - The relation is a universal function of λ and T independent of a particular sample

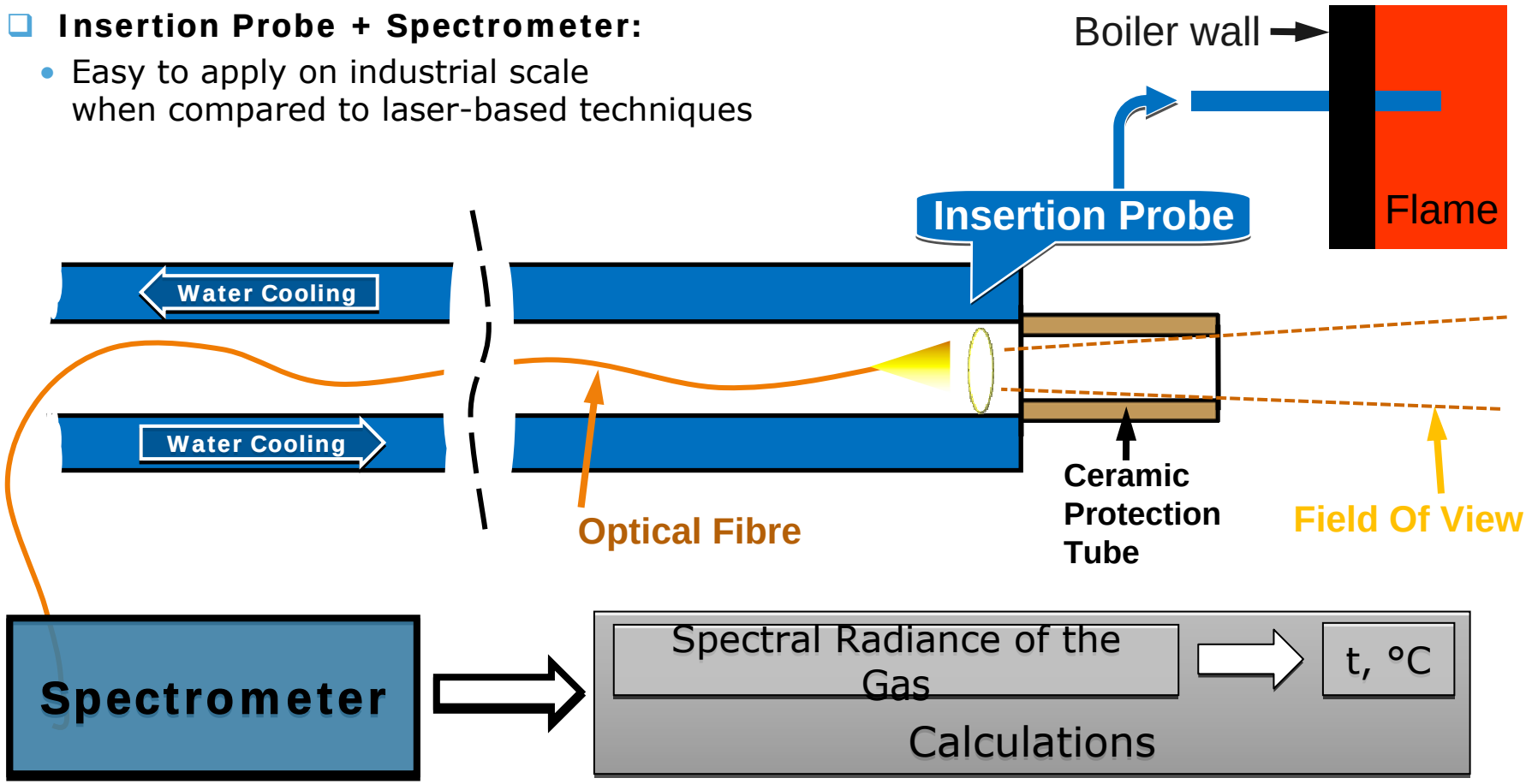
$$\frac{R_\lambda(T)}{\alpha_\lambda(T)} = R_\lambda^{univ}(T)$$

- Planck derived that function:
  - **Temperature can be calculated** from measured
    - spectral absorptivity
    - spectral radiance

$$R_\lambda^{univ}(T) = \frac{c_1}{\pi \lambda^5 (e^{c_2/\lambda T} - 1)}$$

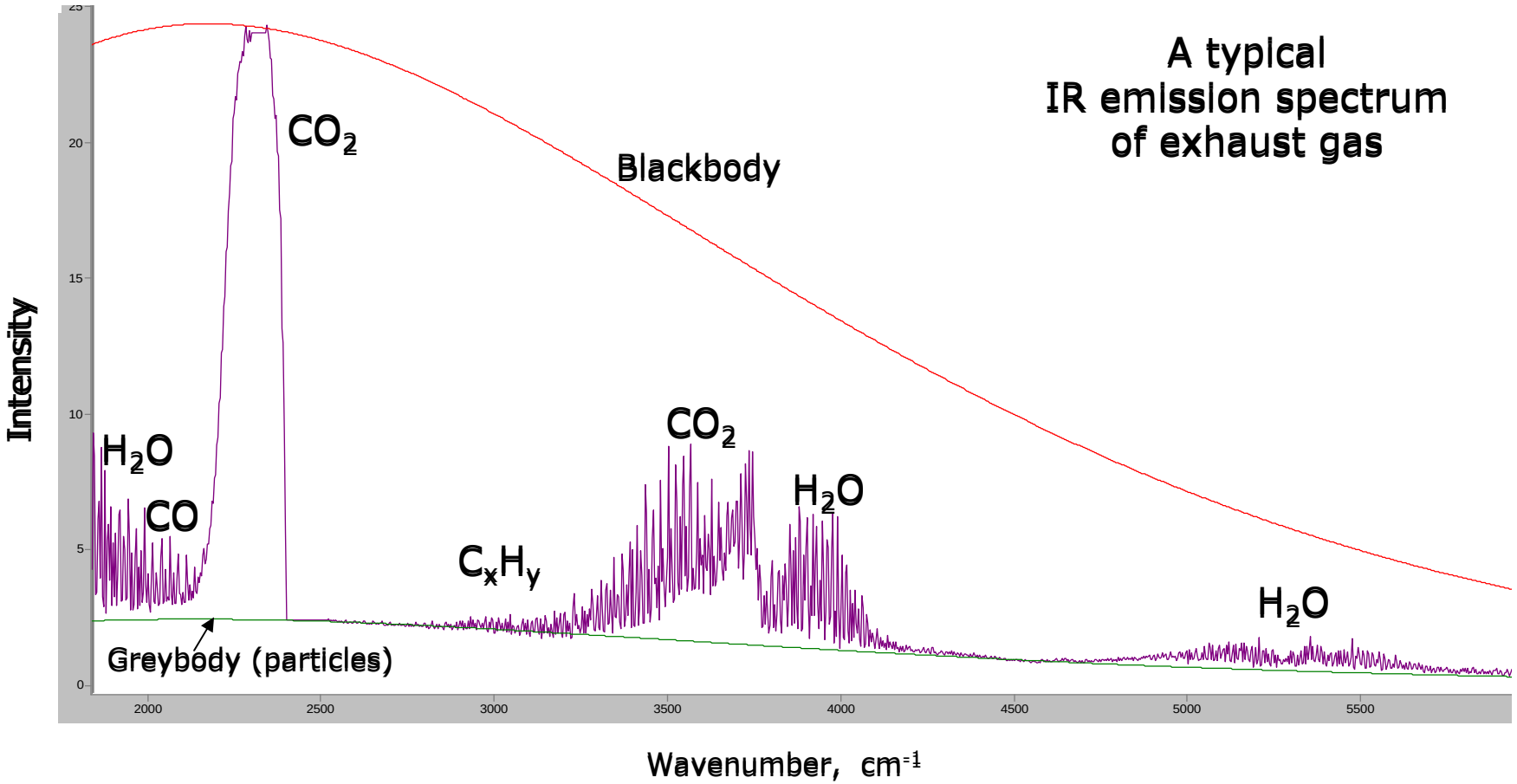
Non-Contact Methods

- **Insertion Probe + Spectrometer:**
  - Easy to apply on industrial scale when compared to laser-based techniques

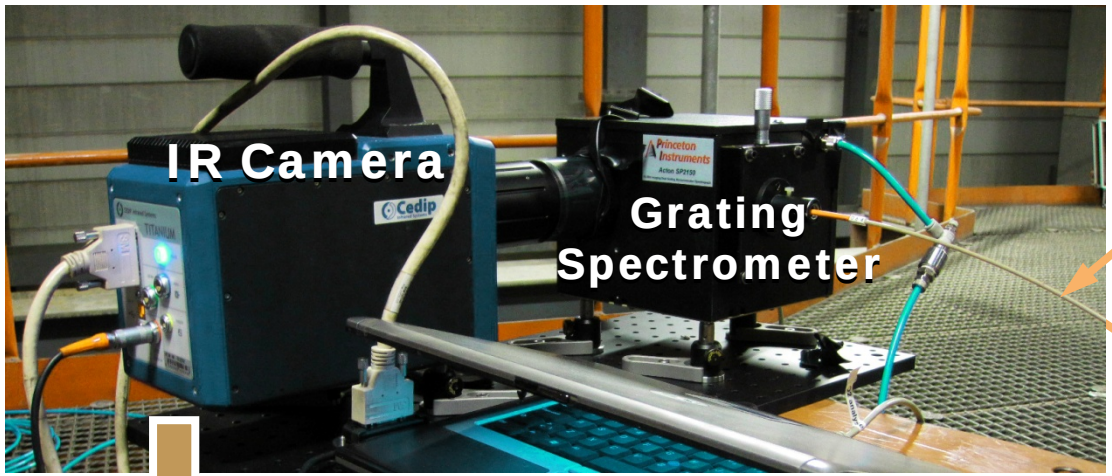


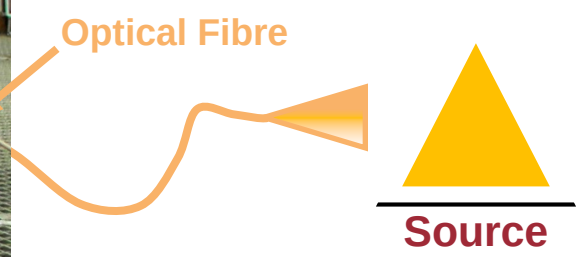
- **Temporal resolution is determined by the spectrometer**
  - *Fourier Transform Infra Red (FTIR) spectrometer*: 2 Hz
    - Still not enough to resolve fast temperature variations

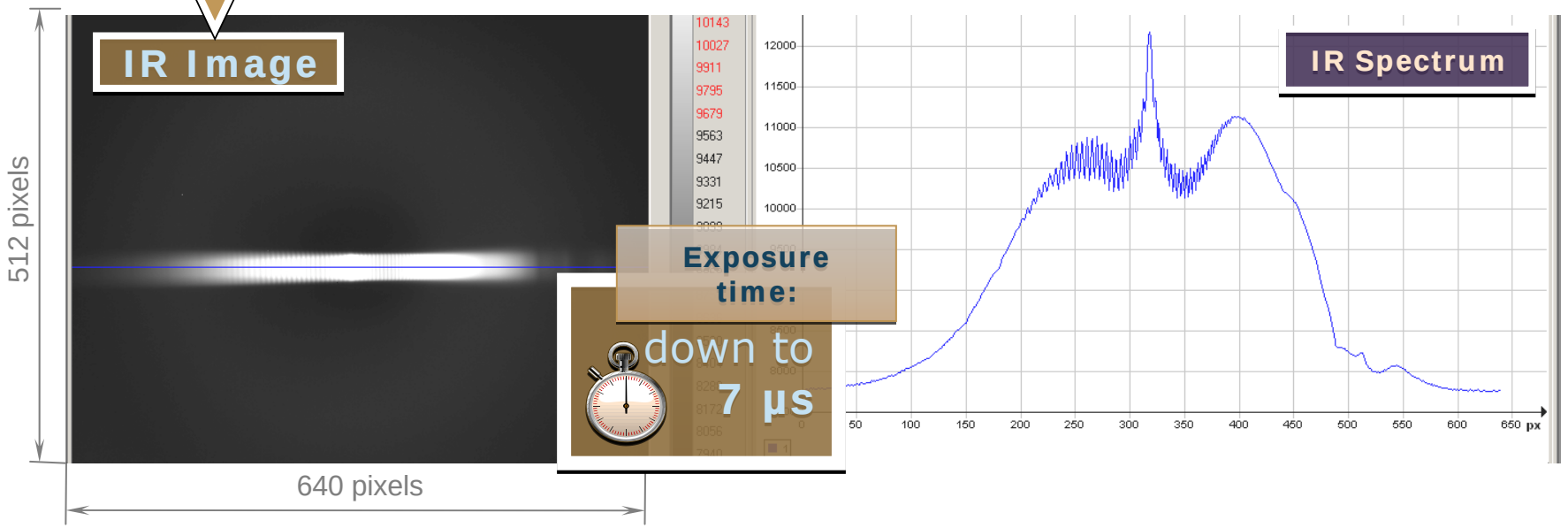
IR Emission Spectrum



A New System


IR Camera
Grating
Spectrometer
Princeton Instruments
Cedip

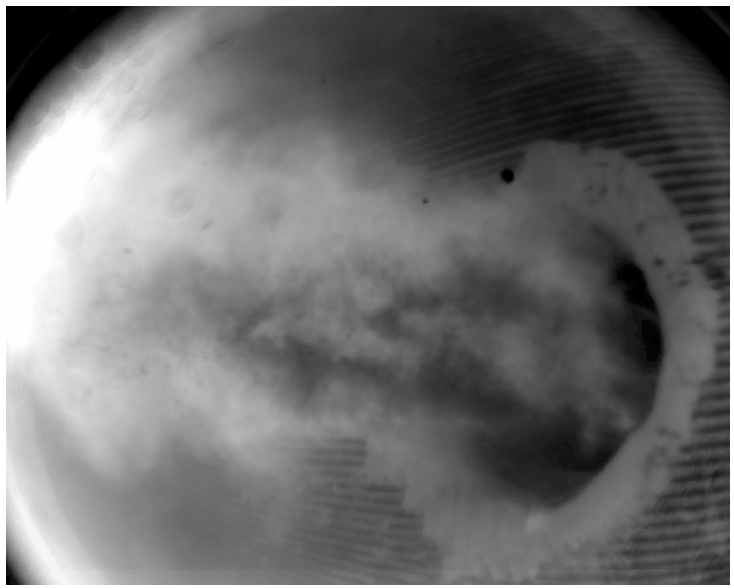

Optical Fibre
Source


IR Image
512 pixels
640 pixels
10143
10027
9911
9795
9679
9563
9447
9331
9215
12000
11500
11000
10500
10000
Exposure time:
down to
7 µs
IR Spectrum
50
100
150
200
250
300
350
400
450
500
550
600
650
px

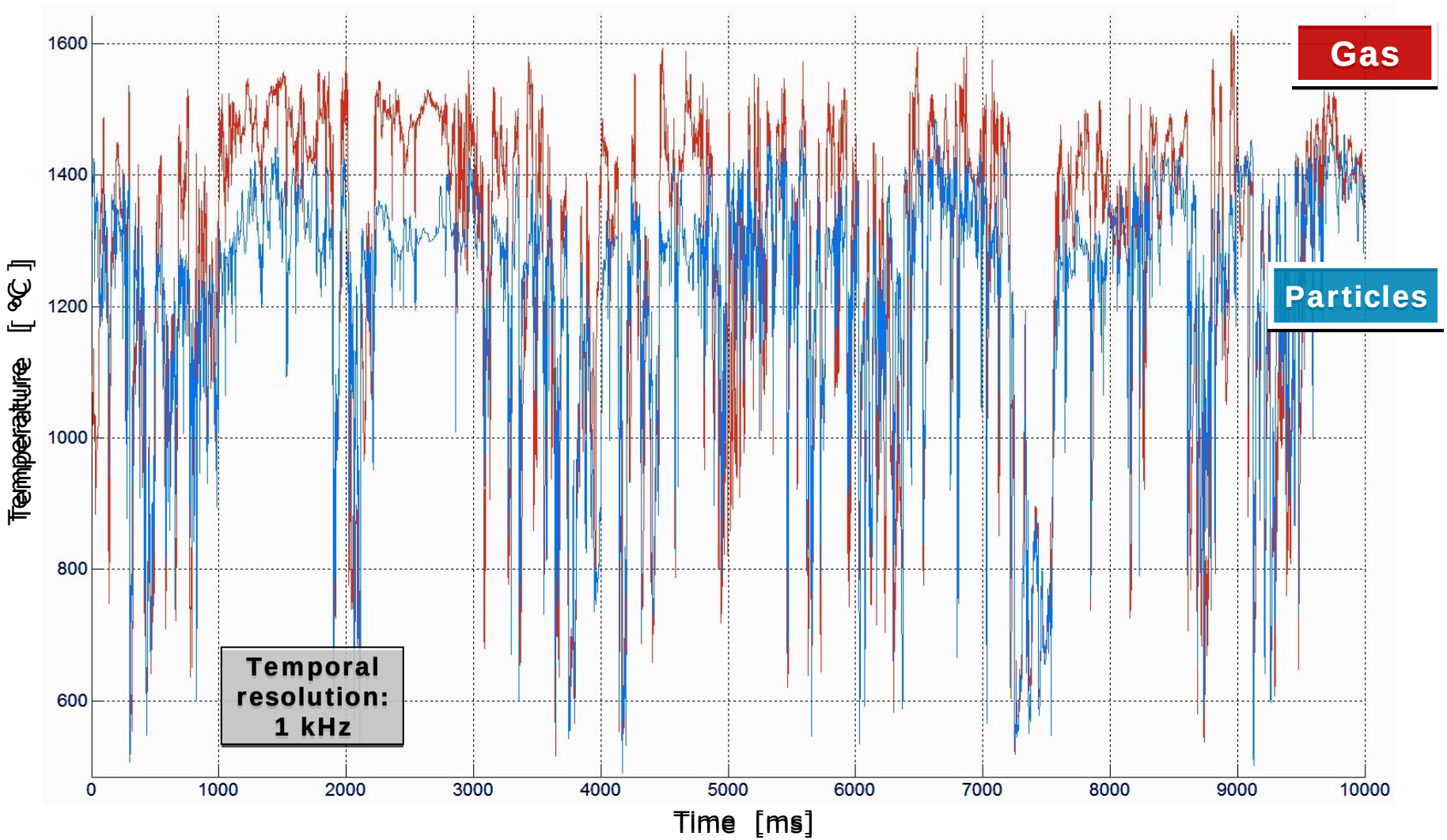
Industrial Boiler

- **The boiler of a biomass-coal power station**

- Thermal picture of the 40 MW flame

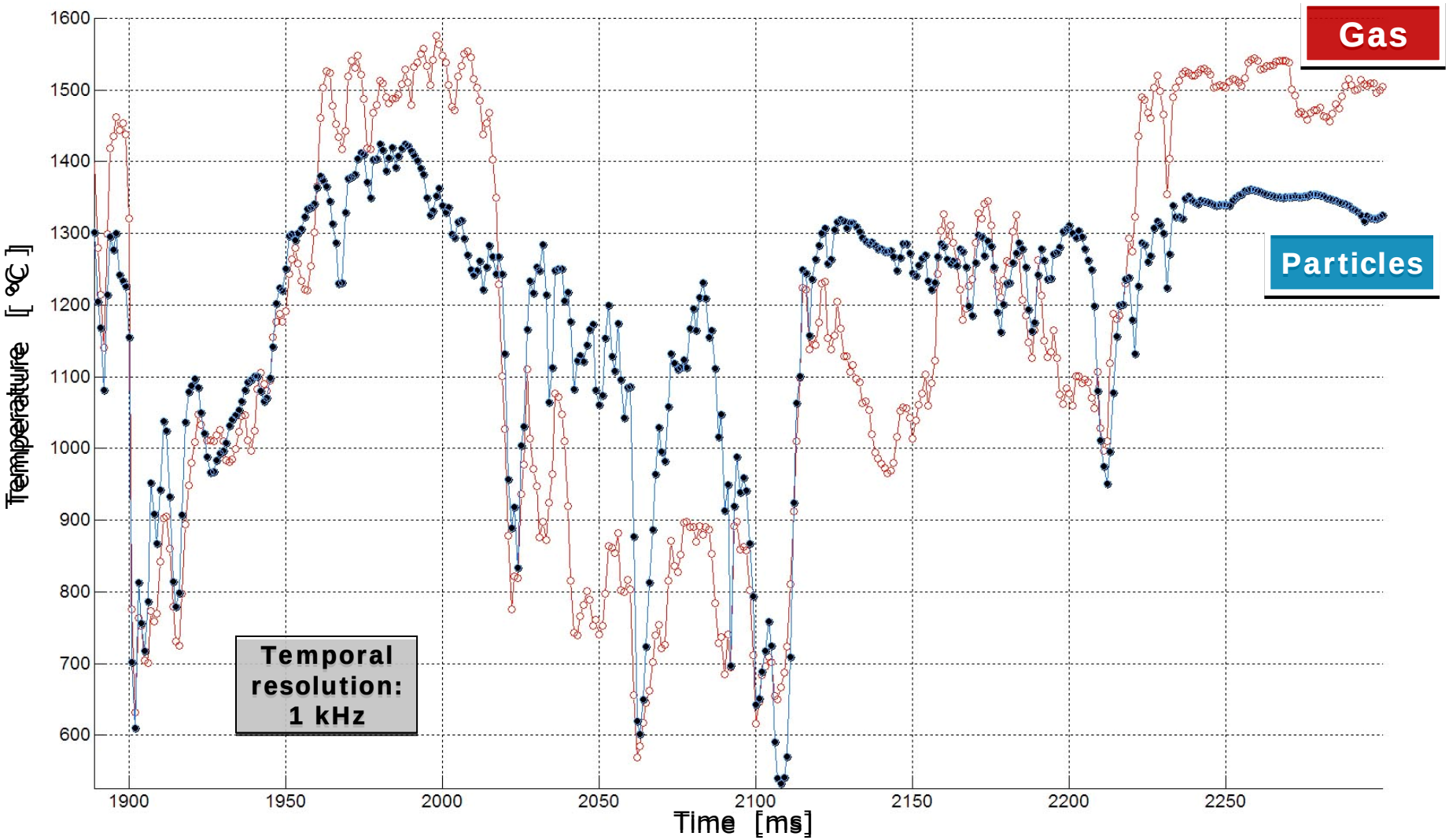


Temperature Variations: A Straw Region Near the Burner Outlet



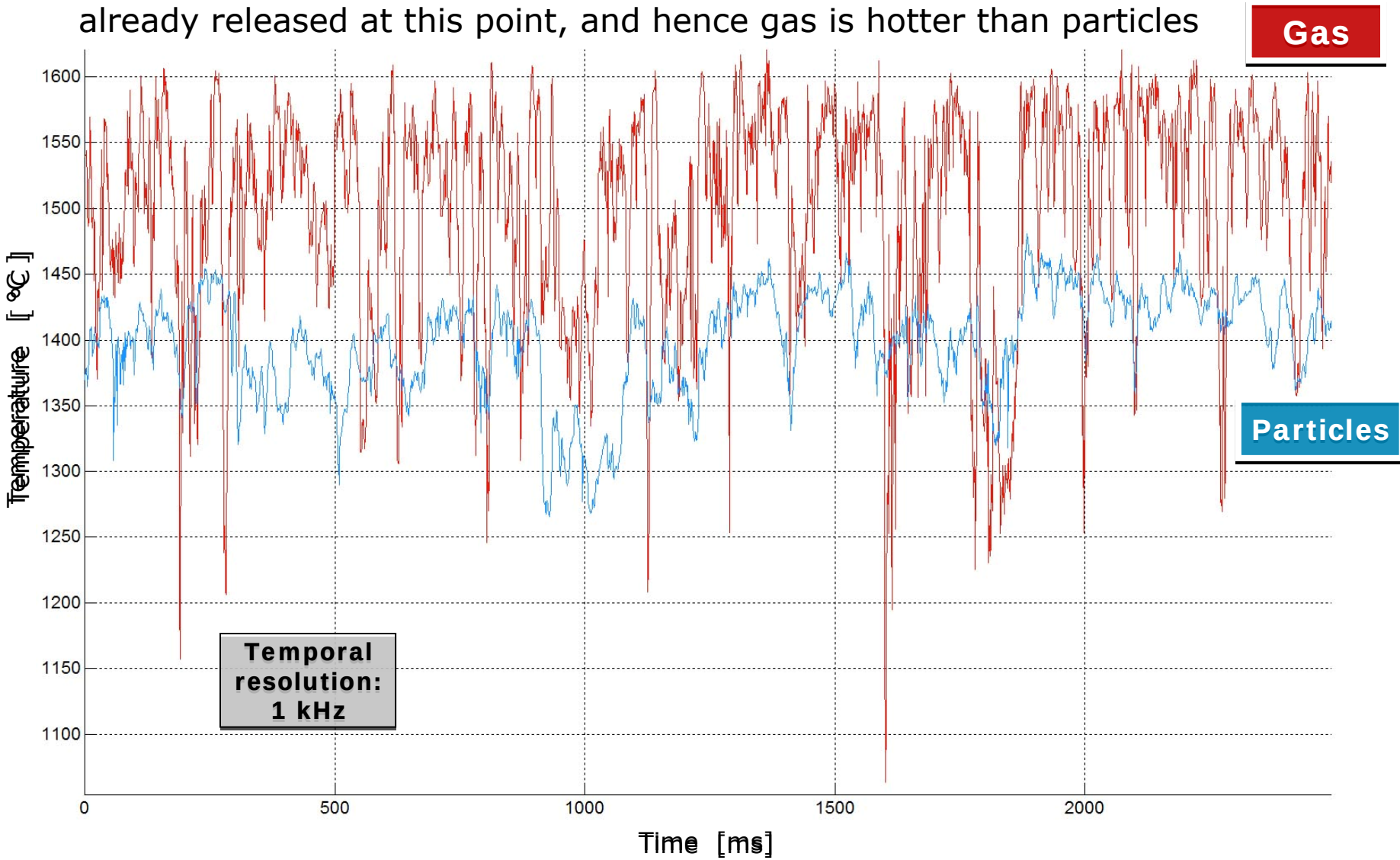
Temperature Variations: A Straw Region Near the Burner

- **Zoom In:** 1kHz is enough to resolve temperature variations in the flame



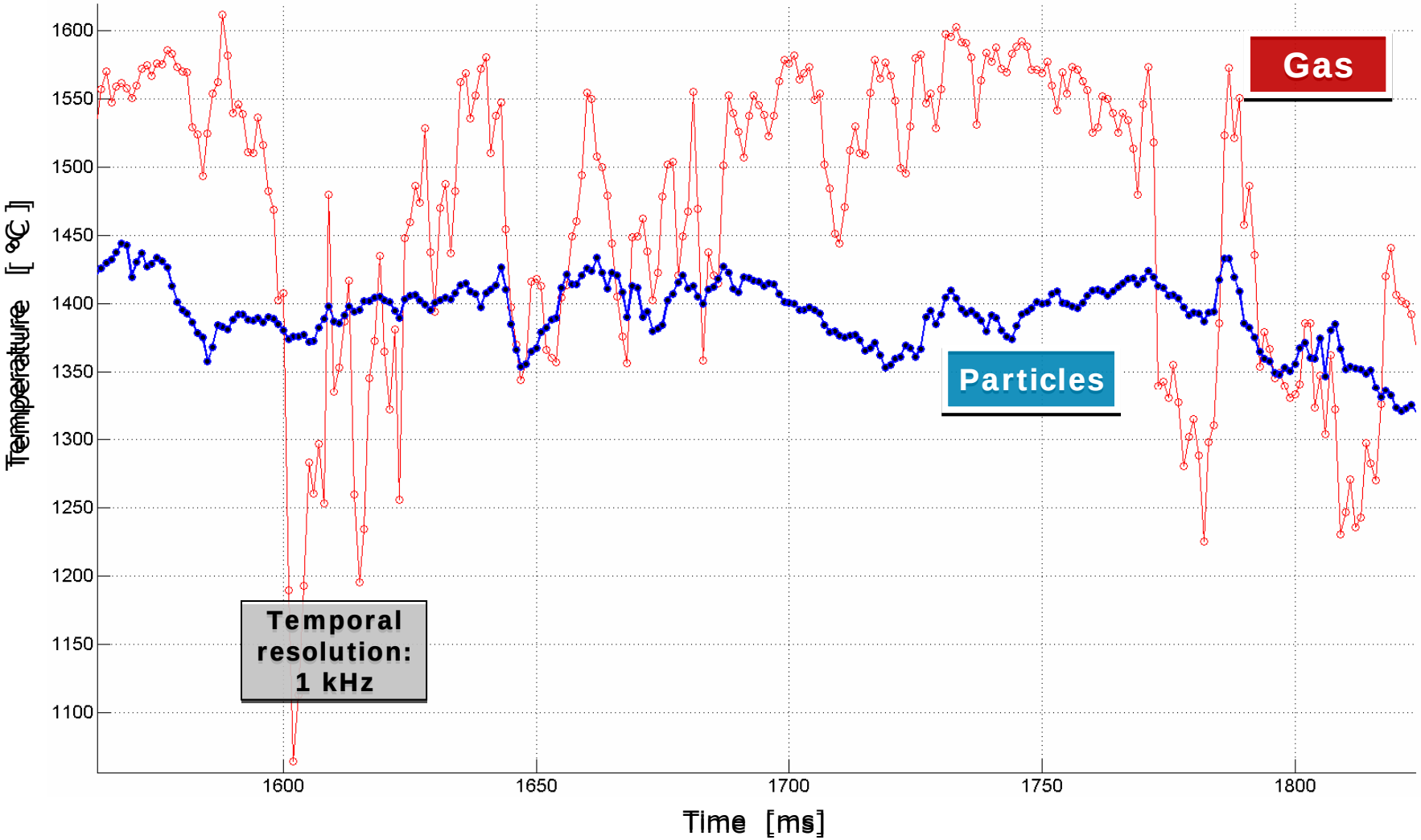
Temperature Variations: Above the Straw Region

- Here gas temperature is higher than that of particles. Most of heat is already released at this point, and hence gas is hotter than particles



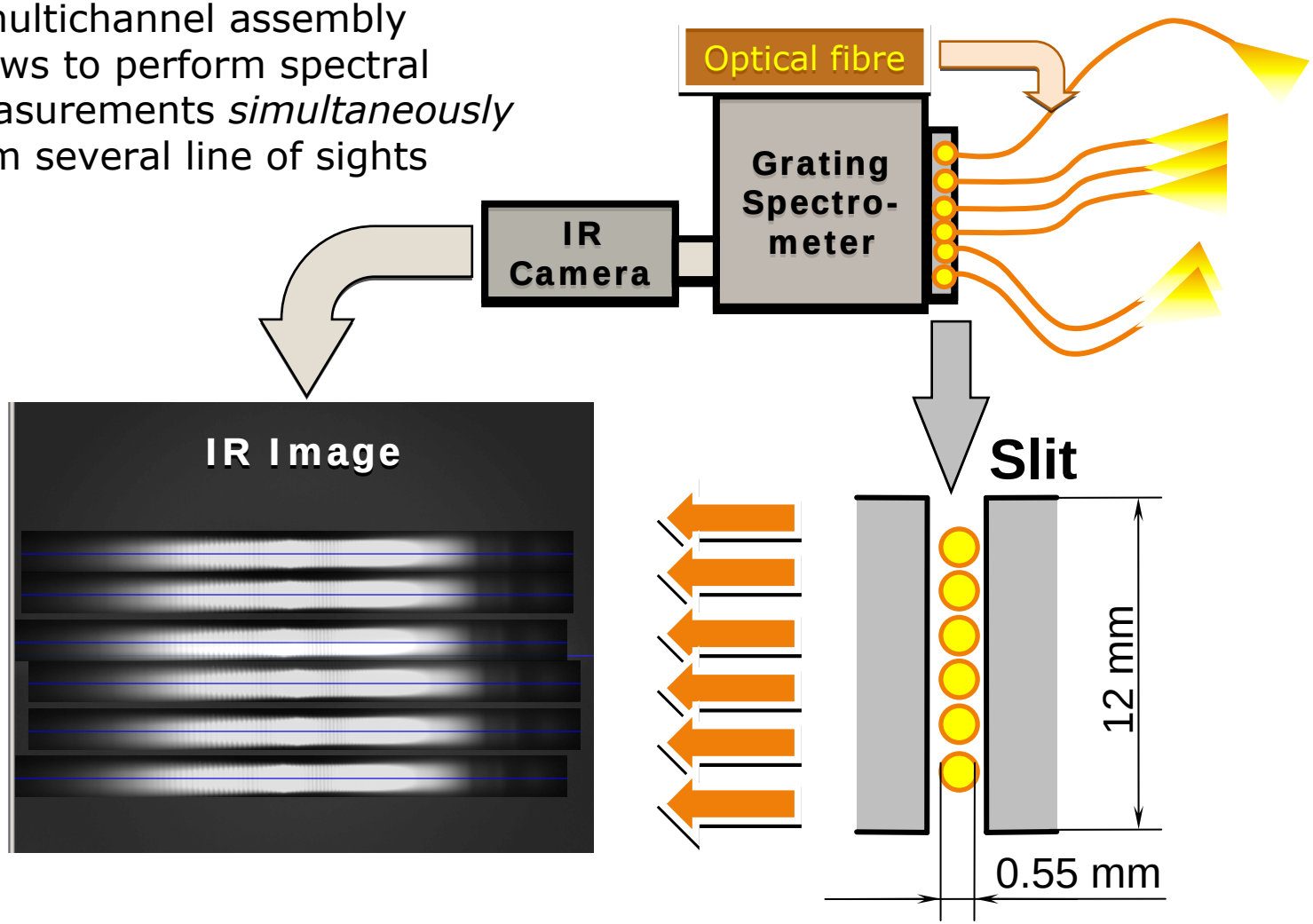
Temperature Variations: Above the Straw Region

- **Zoom In:** Particles do not undergo as huge temperature variations as gases do



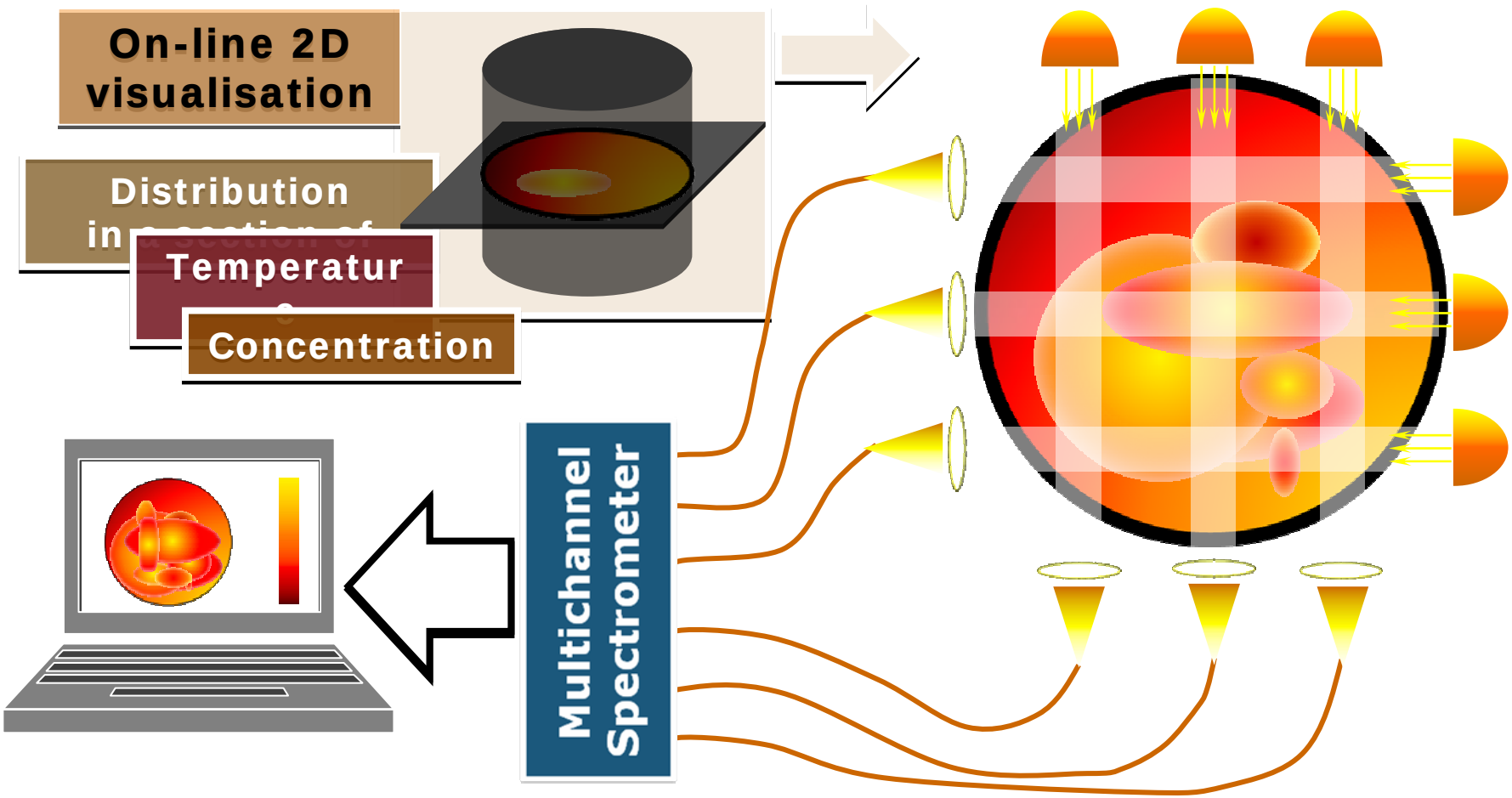
Multichannel IR Spectrometer

- A multichannel assembly allows to perform spectral measurements *simultaneously* from several line of sights



Simultaneous spectral measurements

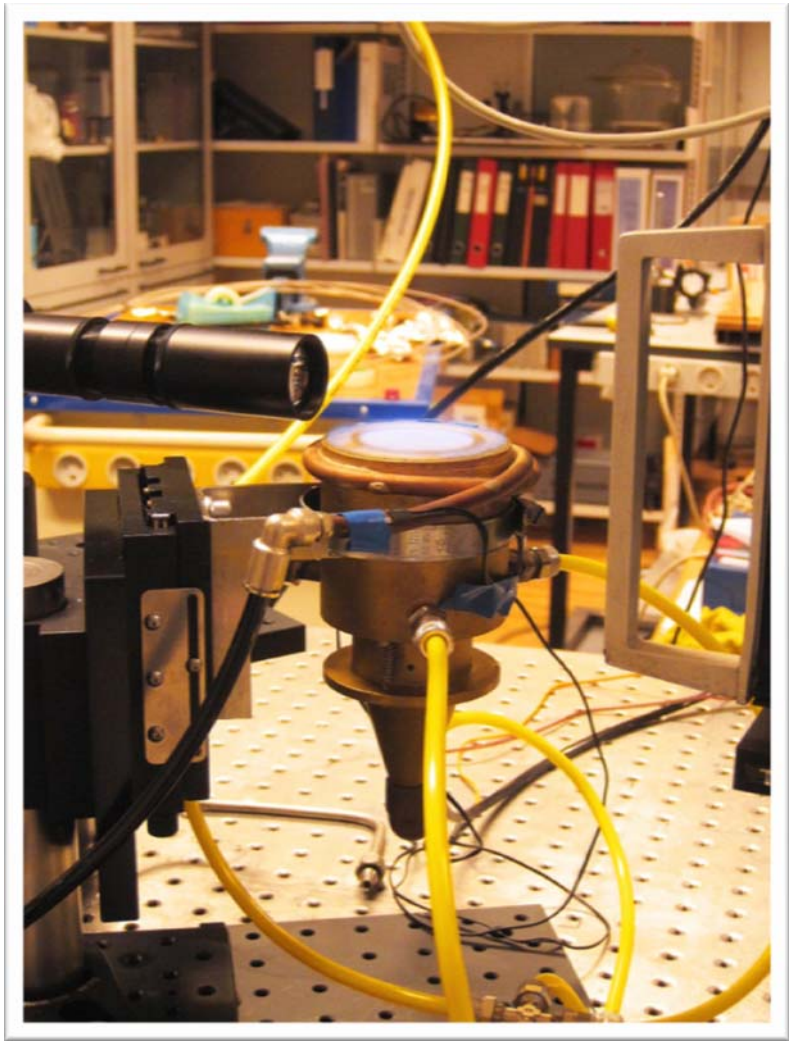
2D Tomography of hot gases



- 2D Tomography of hot gas in an exhaust pipe shows distribution of temperature or gas concentrations in a pipe cross section

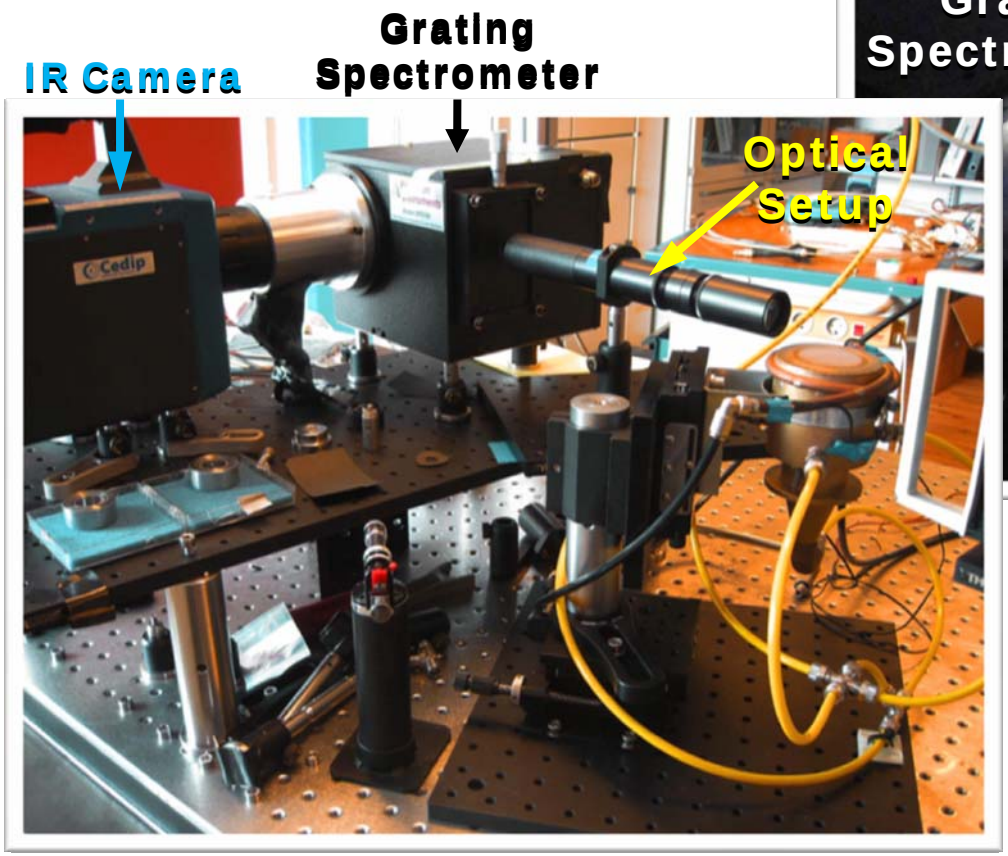
The Flat Flame Burner

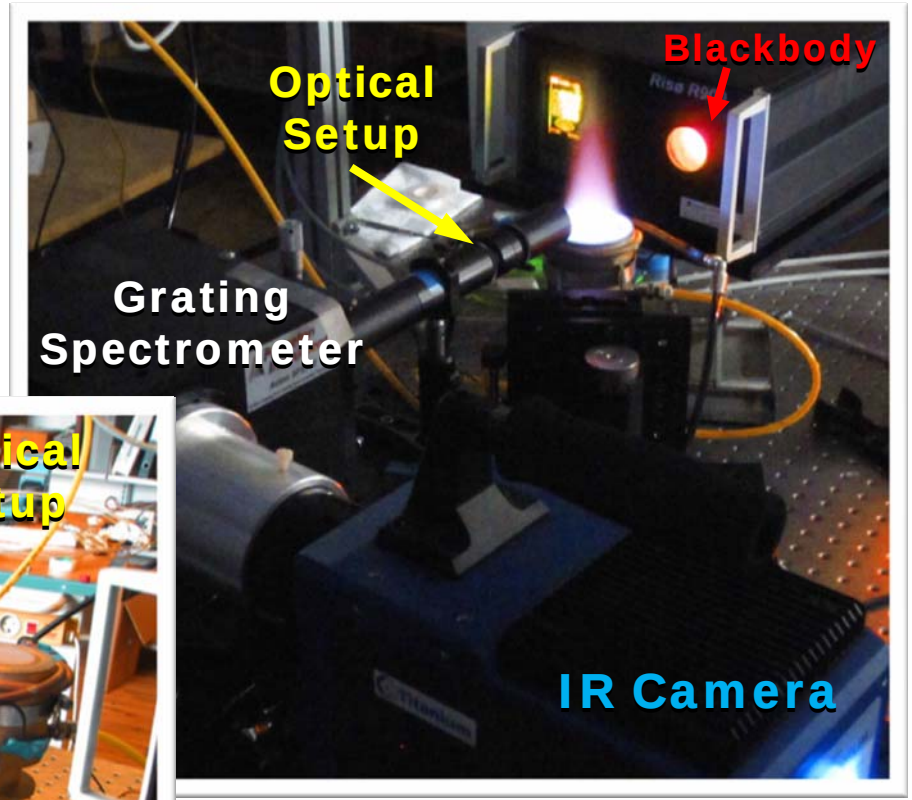
- To develop tomography tools we need a burner producing a stable, flat flame with known temperature profile



The experimental setup

- An optical setup with CaF_2 lenses is used instead of optical fibers to improve the performance of the spectral measurements





Conclusions

- **Temperature and concentrations of combustion gases can be measured from their emission spectra**
  - e.g. spectrum of hot CO_2 can be used for the measurements of flue gas temperature

- **Grating spectrometer + IR Camera is a smart solution to provide**
  - spectral measurements with high temporal resolution
  - possibility of commercial applications on an industrial scale

- **This system provides high flexibility and is promising in further developments**
  - simultaneous spectral measurements at several lines of sight
  - 2D Tomography of hot gases and flames